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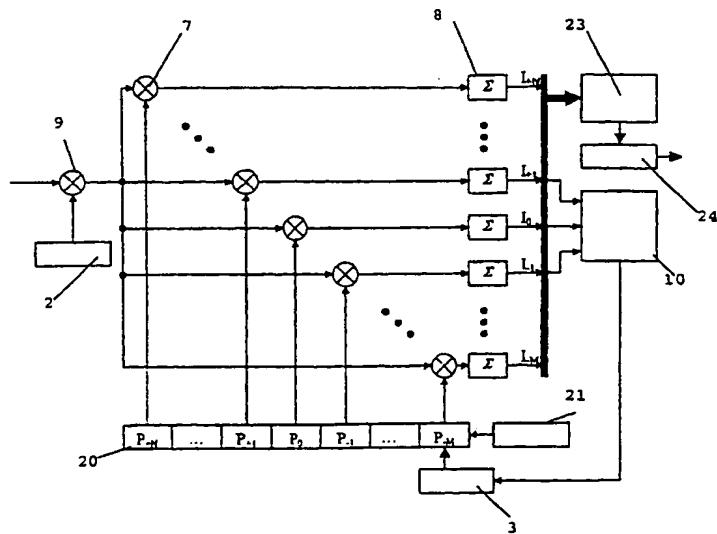
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(54) Title: METHOD AND APPARATUS FOR PROCESSING SIGNALS FOR RANGING APPLICATIONS



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(57) Abstract: The present invention is related to a method and apparatus for processing a signal sent by a transmitter to a receiver, in particular for ranging applications. The signal is typically sent by a satellite, and comprises a carrier signal, modulated by at least one pseudo random noise code and a navigation signal. The method of the invention comprises a step of estimating the multipath error at each calculation of the range. The estimation is done by a multipath estimator module (23) on the basis of a predefined formula. Said formula is based on the calculation of at least four correlation values between at least four different versions of the PRN code and the PRN encoded signal sent by the transmitter.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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METHOD AND APPARATUS FOR PROCESSING SIGNALS FOR RANGING
APPLICATIONS

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Field of the invention

[0001] The present invention is related to a method and apparatus for receiving and processing signals, essentially signals of the spread spectrum type, such as 15 are used in the Global Positioning System (GPS).

State of the art

[0002] Today, satellite based positioning systems are widely in use. Most known are the Global Positioning 20 System (GPS) developed by the United States Government or the Global Navigation Satellite System (GLONASS) developed by the Russian Government. The primary purpose of these systems is to provide position, velocity and time to any user on or near the Earth's surface. The user determines 25 his position in space and time by measuring his range to at least 4 satellites whose position and time are accurately determined, the range being defined as the distance between the user and a satellite.

[0003] The GPS satellites transmit signals on two 30 carrier frequencies called L1 at 1575.42 MHz and L2 at 1227.6 MHz. The carriers are modulated by pseudo-random (PRN) spreading codes that are unique to each satellite, and by a navigation message. All satellites transmit at the same frequencies. The separation between the

satellites is possible because all the PRN codes are chosen to be orthogonal.

[0004] The L1 carrier is modulated by the so-called coarse/acquisition code ("C/A-code") and the precision code ("P-code"). The C/A-code has a chipping rate of 1.023 MHz and a length of 1 ms, thus it contains 1023 chips (the term "chip" is used for the code symbols). The same 1023 chips are repeated every millisecond. The P-code has a chipping rate of 10.23 MHz and a length of 1 week. The same pattern is thus repeated every week. The L2 carrier is modulated only by the P-code. The signal bandwidth at L1 and L2 is limited in the satellite to the main lobe of the P-code spectrum, i.e. 20.46 MHz.

[0005] In addition to the PRN code modulation, each of the carriers is also modulated by a 50-Hz navigation message, conveying all the necessary parameters to compute the satellite position and time.

[0006] Signal tracking involves synchronising local replicas of the carrier and PRN codes of the satellite to be tracked with the incoming carrier and PRN codes from that satellite. This means that the receiver must have the ability to generate the PRN codes of all the satellites.

Signal tracking is achieved by continuously modifying the phase and frequency of the carrier replica and delaying or advancing the code replica in order to maintain them locked on the incoming signal. Carrier tracking is accomplished in a phase lock loop (PLL), while code tracking is performed by a delay lock loop (DLL). By definition, when synchronisation is achieved, the phase of the carrier replica is the same as the incoming carrier phase, and the delay that had to be applied to the code replica is the same as that of the incoming code.

[0007] The range measurement by a GPS receiver is based on the measurement of that delay, which is a direct

measure of the signal travel time from the satellite to the receiver. By multiplying the delay by the speed of light, the receiver computes its range to the satellite.

[0008] Several error sources influence the accuracy 5 of the satellite range measurement. One of the most cumbersome of them is the multipath error. Multipath is a special type of interference where the received signal is composed of the desired line-of-sight signal, and one or more constituents which have traversed slightly different 10 paths due to reflections on surfaces or objects in the antenna surroundings. Multipath signals arrive at the receiver with a different delay, phase and power than the line-of-sight signal.

[0009] The ranging error due to multipath depends on 15 the delay, phase and power of the multipath signal with respect to the line-of-sight signal, and on the type of signal processing the receiver uses. Several digital processing techniques have been devised to reduce the effect of multipath on the ranging measurements.

20 [0010] However, a common drawback of the available multipath mitigation methods is that they are not able to reduce multipath having a short delay. Even for the most recent multipath error mitigation techniques, multipath arriving at the receiver with a delay of less than around 25 20 m affect the range measurement as if no mitigation technique were used at all. This is a serious limitation of the current techniques because in real life situations, most of the multipath signals are of short delay type.

[0011] Document US-A-5390207 is related to a 30 receiver for pseudorandom noise encoded signals. The operation of the device is based on narrowing the early-late spacing, to a fraction of a PRN code chip time, in order to mitigate multipath errors. The use of early-late correlators is a known technique for locking onto an

incoming PRN code, and the early-late spacing, i.e. the time spacing between early and late versions of the local PRN code is an important parameter when it comes to multipath error mitigation. The exact definition of this 5 term is given in the next paragraph.

[0012] Document US-A-5734674 is equally related to a receiver for PRN encoded signals; the receiver described in this document has the capability of dynamically adjusting the early-late spacing between correlation signals.

10 [0013] Document US-A-5809064 is related to improvements to the same type of receiver as described in US-A-5734674, and equally based on dynamically adjusting early-late spacing.

15 [0014] All techniques related to adjusting and essentially reducing the early-late spacing are linked to a modification of the DLL discriminator. A general name for these techniques is 'narrow spacing', as opposed to techniques wherein no multipath error mitigation takes place ('wide spacing' techniques). It is found that prior 20 art 'narrow spacing' techniques reduce the maximum range error with a factor 10 compared to 'wide spacing' techniques. However, an important multipath error remains for a wide range of multipath delays.

25 [0015] Document US-A-5414729 is related to a receiver for PRN encoded signals, wherein a plurality of correlation signals are fed to a parameter estimator, from which the delay, amplitude and phase parameters of the direct path signal, as well as any multipath signals, may be estimated. This estimation however takes place by 30 solving a system of equations, for example through a least squares calculation, which requires complex and expensive hardware and software capabilities.

[0016] Document US-A-5953367 is related to a receiver for PRN encoded signals, comprising a plurality of

DLL correlators provided in each of the receiver's multiple processing channels. These correlators are combined in such a way as to build a DLL discriminator which is not affected by most of the multipath errors. This improves 5 the tracking in the presence of multipath, but requires a significant modification of the DLL architecture, in comparison to wide spacing and narrow spacing DLL's.

[0017] Document US-A-5901183 is related to a receiver for PRN encoded signals, wherein both the receiver 10 DLL code and PLL carrier loops include a loop component that senses an error in its main loop caused by the presence of a multipath signal. A compound correlator loop is formed of a primary correlator and a secondary correlator that senses and corrects for multipath induced 15 tracking error of the primary correlator.

[0018] The three latter documents represent the closest prior art, in that they describe methods which allow a total elimination of multipath errors for a wide range of multipath delays. However, at multipath delays of 20 less than 20m, which are the most common in practice, even these techniques fail to have any influence on multipath errors.

[0019] An overview of the capabilities and limitations of prior art methods is given in figure 1. The 25 graph shows the range error envelope for three different signal processing techniques. Each envelope represents the maximum and minimum range error as a function of the multipath signal delay, for a given signal to multipath power ratio; in this case this ratio is equal to 4. The 30 curve 100 refers to 'wide spacing' techniques, i.e. techniques wherein no multipath mitigation is employed. The curve 101 is valid for the 'narrow spacing' techniques referred to above, while the curve 102 corresponds to the techniques described earlier as representing the closest

prior art. It is clear that no prior art technique is capable of reducing multipath errors at the lowest multipath delays (0-20m).

5 Aims of the invention

[0020] The present invention aims to provide a method and a device for receiving and processing signals of the spread spectrum type, allowing a reduction of multipath errors in the lowest range of multipath delays, said 10 reduction being in comparison to the closest prior art.

[0021] The present invention further aims to propose a method and device which are technically straightforward and inexpensive compared to existing methods and devices.

15 Summary of the invention

[0022] The present invention is related to a method for processing at least one signal sent by a transmitter, said signal preferably being used for measuring the range, i.e. the distance between said transmitter and a receiver, 20 said signal comprising a carrier signal modulated by a pseudo random noise (PRN) code, said method comprising the steps of :

- mixing said signal with a replica of the carrier signal, to acquire a baseband signal, representing said PRN 25 code,
- multiplying said baseband signal respectively with at least four PRN code replica's, said replica's being shifted in time with respect to each other,
- calculating the correlation values of said baseband 30 signal with respect to each of said at least four PRN code replica's,
- calculating from said correlation values, an estimate of the multipath error, said calculation being based on a

predefined formula, equating said multipath error to a predefined function of said correlation values (I_{-M}, \dots, I_{+N}).

[0023] In particular, the method includes the actual 5 calculation of the distance between said transmitter and receiver, and thus comprises the steps of :

- mixing said signal with a replica of the carrier signal, to acquire a baseband signal, representing said PRN code,
- 10 - multiplying said baseband signal respectively with three equally spaced replica's of said PRN code, namely an early, punctual and late replica, with a given early-late spacing,
- multiplying said baseband signal with at least one 15 additional replica of said PRN code, said additional replica being shifted in time relative to said early, late and punctual replica's,
- calculating the correlation values of said baseband signal with respect to each of said at least four PRN 20 code replica's,
- locking the punctual code to the baseband signal by keeping the two correlation values between said baseband signal and said early and late replica's equal to each other,
- 25 - calculating the range by multiplying the delay of the punctual code by the speed of light,
- calculating from said correlation values, an estimate of the multipath error, said calculation being based on a predefined formula,
- 30 - filtering said estimate of the multipath error and subtracting said estimate of the multipath error from said calculated range, yielding a corrected range value.

[0024] Preferably, said predefined formula is a linear combination of said correlation values, each of said values being normalised by the correlation value of said punctual replica.

5 [0025] According to the preferred embodiment, said linear combination is of the following form :

$$MP = \sum_{i=-M..N} \alpha_i \frac{1}{I_0} \frac{I_i}{1 - |i| \frac{d}{2}}$$

10 wherein MP represents the multipath error, d represents the early-late spacing, I_0 represents the correlation value of said punctual replica, I_{-M}, \dots, I_{+N} represent the correlation values, α_i represent one or more predefined values.

15 [0026] It is also to be preferred that every one of said at least four replicas is shifted over the same time delay with respect to the next and/or previous replica.

20 [0027] According to the preferred embodiment of the invention, four replica's are used, the early-late spacing is 1/15 of a chip length, the fourth replica (P_{+2}) is 1/15 of a chip length later than said punctual replica (P_0), and said multipath error estimation (MP) is calculated as :

$$MP = -0.42 \cdot \left(1 - \frac{I_{+2}}{I_0} \frac{1}{1-d} \right)$$

25 [0028] The present invention is equally related to a receiver for ranging applications according to the method of the invention, said receiver comprising a plurality of channels for detecting and locking onto a plurality of PRN encoded signals, each channel comprising :

- a delay line, comprising at least four taps,
- a plurality of mixers and accumulators to calculate said

30 at least four correlation values,

- a multipath estimator module to calculate said multipath error estimate,
- a low pass filter.

[0029] According to a first embodiment of the 5 receiver of the invention, said multipath estimator module comprises software means for calculating the multipath error estimate on the basis of a predefined formula.

[0030] According to a second embodiment, said 10 multipath estimator module comprises hardware means for calculating the multipath error estimate on the basis of a predefined formula.

Short description of the drawings

[0031] Fig. 1 illustrates the ranging error 15 envelopes for prior signal processing techniques.

[0032] Fig. 2 illustrates the signal processing in a receiver for a ranging application according to the prior art.

[0033] Fig. 3a and 3b illustrate the effect of 20 multipath errors on the tracking point in devices of the prior art.

[0034] Fig. 4 illustrates the general concept of the method and device of the invention.

[0035] Fig. 5a and 5b illustrate the principle of 25 the multipath estimator module.

[0036] Fig. 6 represents a preferred embodiment of the invention.

[0037] Fig. 7 compares the invention to the prior art in terms of ranging error envelope.

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Detailed description of the invention

[0038] A typical implementation of the signal processing technique according to the prior art for ranging

applications is represented in Fig. 2. The incoming signal 1 is first mixed with a local replica of the carrier, produced by the carrier generator 2, in order to bring the signal to baseband. The frequency and phase of the local 5 carrier are controlled by a PLL (not shown). The baseband signal essentially represents the PRN code, modulated by the 50Hz navigation signal.

[0039] The delay lock loop is represented by the group of elements 4. As known in the art, an acquisition 10 step is first performed in order to acquire a 'coarse' match between the incoming signal and a local version of the PRN code. After that, the local code needs to be locked onto the incoming signal. The present invention is related to this locking step.

[0040] Referring again to figure 2, the local PRN code is generated in the code generator 3 at a rate which is continuously controlled by the DLL discriminator and filter 10. The code enters a delay line 5 where three 20 different code replicas are generated : P_0 is the punctual code replica, which has to be kept aligned with the incoming code. P_{-1} is the early replica, which is advanced by a fraction of a chip with respect to P_0 , and P_{+1} is the late replica, delayed by a fraction of a chip with respect to P_0 . The delay between any two adjacent taps in the 25 delay line is the inverse of the frequency of the delay line clock 6, and is traditionally referred to as "d/2" in units of code chips.

[0041] For the GPS C/A-code, the code chip duration is close to 1 μ s, and the chip length close to 293 m. The 30 delay between the early and late taps is an important design parameter, which is referred to as the early-late spacing, and noted 'd'. Many receivers use a so-called

"Wide spacing" of $d = 1$ code chip. The spacing is said to be narrow if d is lower than 1 chip.

[0042] Returning to figure 2, the multipliers 7 followed by the accumulators 8 compute the correlation 5 between the baseband signals at the output of the carrier mixer 9 and each of the local code versions. The resulting three correlations I_0 , I_{-1} and I_{+1} are represented in Fig. 3a as a function of the delay misalignment $\Delta\tau$ between the incoming code and the local punctual code (P_0). Fig. 3a 10 corresponds to the case where no multipath signals are present. When $\Delta\tau$ is positive, the local punctual code is late with respect to the incoming code, and the early correlation (I_{-1}) is higher than the late correlation (I_{+1}). The opposite occurs when $\Delta\tau$ is negative. As can be 15 expected, the correlation between the punctual and the incoming code (I_0) reaches its peak when they are aligned, i.e. when $\Delta\tau = 0$.

[0043] The role of the DLL 4 is to keep the punctual code P_0 aligned with the incoming code. It is apparent 20 from the figure 3a that this is achieved if the two side correlations I_{-1} and I_{+1} are equal. Therefore, the DLL is designed such that it adapts the frequency of the local code in such a way that the equality $I_{-1}=I_{+1}$ is verified. As long as the DLL succeeds in doing that, the punctual 25 code P_0 is locked on the incoming signal.

[0044] This implementation gives the correct tracking point in absence of multipath. However, when multipath is present, the correlations represented in Fig. 3a do not apply any more. The I_0 , I_{-1} and I_{+1} correlation 30 values are the sum of the correlation of the local code with the incoming line-of-sight signal and of the correlation of the local code with the incoming multipath signal. The result is that the correlation profile is

distorted. Fig. 3b illustrates the distortion of the correlation functions in the case of the presence of one multipath signal having a delay of 60 m, and a fourth of the power of the direct signal, and being in phase with the 5 incoming signal.

[0045] It can be seen that the tracking point, defined by the equality $I_{+1} = I_{-1}$, is no longer positioned at $\Delta\tau = 0$. This means that the DLL is not able to correctly align the punctual code and the incoming code. 10 There is a tracking error, which in Fig. 3b is around 0.1 chips, or 30 meters. This tracking error directly translates into an equivalent range error.

[0046] The early-late spacing has a large influence on the sensitivity of the DLL to multipath signals. For 15 example, the envelope noted "Narrow spacing" (curve 101) in Fig. 1 corresponds to a spacing of $d = 0.1$ chips. The amplitude of the horizontal parts of the error envelope 101 in Fig. 1 is proportional to d .

[0047] The state-of-the-art techniques to reduce the 20 range errors caused by multipath rely on a modification of the DLL so that the deviation of the tracking point with respect to the $\Delta\tau = 0$ condition is kept as small as possible in presence of multipath. As discussed above, many prior art techniques are based on a reduction and/or a 25 dynamic adjustment of early-late spacing d , in order to mitigate multipath errors. Others employ elaborate calculation techniques.

[0048] The present invention uses a different 30 approach, based on a known fact, namely that the signal amplitude measurement (or equivalently the carrier-to-noise ratio measurement) reported by a receiver is highly correlated with the range error caused by multipath. This is disclosed in the document "Multipath Mitigation,

Benefits from Using the Signal-to-Noise Ratio", J.M. Sleewaegen, Proceedings of the ION GPS-97 Meeting, pp.531-540, 1997. One of the key properties of the signal amplitude measurement is that it is most sensitive to short 5 multipath delays. The present invention makes use of this property to derive a multipath error estimator that is operating even for short multipath delays.

[0049] In the invention, a conventional narrow spacing DLL is used for the tracking, i.e. a DLL with a low 10 early-late spacing, for example $d = 1/15$ of a chip length. Tracking is thus performed in the classic way, i.e. by keeping the early and late correlation values equal to each other (see figure 3b). At least one additional correlation value is calculated, based on at least one additional 15 replica of the PRN code, shifted in time with respect to the punctual, early and late versions. The multipath errors are estimated a posteriori by an independent multipath estimator module, on the basis of a predefined formula, comprising at least the correlation value between 20 the incoming signal and said at least one additional PRN code replica. The method of the invention yields a minimum impact on the tracking process, and allows to easily turn on or off the multipath estimation process, without modifying the tracking process.

[0050] Figure 4 illustrates the method of the invention, and shows equally the characteristic building blocks that need to be present in a receiver according to the invention. In the conventional implementation shown in figure 2, the correlation peak is measured at three 30 different points, by providing an early, late and punctual version of the code. In the proposed invention, the correlation peak is measured with respect to the same three versions of the code, and in addition to at least one more version, shifted in time with respect to the first three.

[0051] According to the general case presented in figure 4, $M+N+1$ correlation values are computed, namely M early versions (P_{-M}, \dots, P_{-1}), one punctual version (P_0), and N late versions (P_{+1}, \dots, P_{+N}). This is done by using a delay line 20 having $M+N+1$ taps, commanded by a delay line clock 21 and generating $M+N+1$ versions of the local code. The delay between the taps is still noted $d/2$, and the delay between tap i and tap 0 is $id/2$ ($i=-M, \dots, +N$).

[0052] As in the prior art receiver, a carrier generator 2 and code generator 3 are used, and a plurality of mixers 7 and accumulators 8. All these elements in themselves are identical to the ones used in the prior art receivers. For the tracking, a conventional DLL discriminator and filter 10 is used, to perform tracking in the classic way, namely based on one early (P_{-1}), one punctual (P_0) and one late PRN version (P_{+1}). Independently, all the $M+N+1$ correlation values (I_{-M}, \dots, I_{+N}) are fed into the multipath estimator module 23 at each calculation of the range. This module derives $M+N+1$ independent estimates of the signal amplitude by scaling each of the $M+N+1$ correlation values by $1/(1-|i|d/2)$, $i=(-M, \dots, N)$. When multipath is present, each of these signal amplitude estimates exhibits an error which is highly correlated with the range error, although it is different for each estimate. The invention lies in taking advantage of these differences to build a multipath range error estimator. More specifically, it can be shown that an appropriate linear combination of the $M+N+1$ signal amplitude estimates, normalized by the punctual correlation value I_0 closely matches the ranging error due to multipath. In other words, the range error due to multipath may be closely approximated by the following formula:

$$MP = \sum_{i=-M..N} \alpha_i \frac{1}{I_0} \frac{I_i}{1 - |i| \frac{d}{2}}$$

This estimation of the multipath error MP is characteristic to the invention. The coefficients α_i are constant. They 5 are computed only once, during the design of the receiver. After the calculation according to the predefined formula, the noise on the estimation (MP) is filtered out by a low pass filter 24. The result is then subtracted from the range derived from the early-late tracking by the DLL, 10 resulting in largely removing the multipath error from the range measurement.

[0053] This predefined formula allows a very fast estimation of the multipath error, compared to existing techniques, in particular compared to the technique 15 presented in US5414729 wherein the multipath error is found at each ranging step, by solving a system of equations. In the method of the invention, no estimation is made of multipath parameters such as delay, phase and amplitude. Only the multipath error itself is estimated.

20 [0054] As an example, and to provide some clarification about the above formula, the following linear combination could be proposed for M=2, N=3 and d=1/15:

$$MP = -0.6 \frac{I_{-2}}{I_0} \frac{1}{1-d} - 0.43 \frac{I_0}{I_0} + 0.48 \frac{I_{+1}}{I_0} \frac{1}{1-d/2} + 0.75 \frac{I_{+2}}{I_0} \frac{1}{1-d} - 0.2 \frac{I_{+3}}{I_0} \frac{1}{1-3d/2}$$

[0055] Fig. 5a and 5b compare the ranging error due to multipath and the estimation of it from the above formula, as a function of the multipath delay, for two different multipath signal amplitudes. In figures 5a and 30 5b, the upper curve corresponds to a multipath component arriving in-phase with the line-of-sight component, the

lower curve correspond to a 180° phase shift. It is apparent that the multipath estimate (curves 30) given by the linear combination given above for $M=2$ and $N=3$, closely matches the range error (curves 31), even for very short 5 multipath delays. The α_i coefficients in the above formula have been optimised to best approximate the error from multipath having an amplitude of one tenth of the direct signal (case of Fig. 5a.). However, the same set of coefficients provides a pretty good approximation of the 10 error for other multipath amplitudes (see Fig. 5b, signal to multipath amplitude ratio = 2).

[0056] A receiver according to the invention allows signal tracking and multipath mitigation according to the method of the invention. Such a receiver comprises a 15 plurality of channels, each channel being able to detect and lock onto a different PRN encoded signal (from a different satellite). Each channel comprises the elements shown in figure 4 : a carrier generator 2, carrier signal mixer 9, delay line 20 and delay line clock 21, local code 20 generator 3, the mixers 7 and accumulators 8 for all PRN versions P_{-M}, \dots, P_{+N} , as well as a DLL discriminator and filter 10, designed for 'narrow spacing' type tracking ($d < 1$ chip). The discriminator and filter may be software based applications, producing command signals to be used as 25 inputs for the local PRN code generator 3. A receiver according to the invention is characterised by the presence of the multipath estimator module 23 and the low pass filter 24. This multipath estimator module can be a software application, that performs the action of 30 calculating the estimated multipath error on the basis of the correlation values (I_{-M}, \dots, I_{+N}) . The estimator may equally be performed in hardware, such as a semiconductor

chip. Also the filter 24 may be a software application or a hardware application.

[0057] The design parameters that have to be optimised in the design of the receiver are the number of 5 correlators $M+N+1$ and the α_i coefficients. They result from a trade-off between receiver complexity, accuracy of the multipath error estimation, and noise on the estimation. Generally speaking, using more correlators (needing to increase the number of taps of the delay line) 10 results in being able to better estimate the multipath error, at the expense of receiver complexity, and noise.

Description of a preferred embodiment of the invention

[0058] Simulations have shown that a good compromise 15 between accuracy of the multipath error estimation and noise on the estimation can be achieved by using only one additional correlator, at position +2 in the delay line ($M=1$, $N=2$), i.e. based on a version of the PRN code that is delayed over a time equal to d with respect to the punctual 20 version. The preferred design is represented in Fig. 6. The components printed in bold are the additional components with respect to the conventional receiver. The multipath estimator 23 of figure 6 computes the following function of its inputs:

25

$$MP = -0.42 \cdot \left(1 - \frac{I_{+2}}{I_0} \frac{1}{1-d} \right)$$

The coefficient -0.42 is the result of an optimisation of the α_i parameters so that the resulting multipath 30 estimation best fits the actual multipath error in the least-square sense, for a wide range of signal-to-multipath

power ratios. In the preferred design, the parameter d is set to 1/15.

[0059] The estimation is then fed to a low pass filter 24. In the preferred design, the low pass filter 5 has a noise equivalent bandwidth B_n of 0.1 to 1 Hz.

[0060] To conclude, Fig. 7 presents a comparison between the multipath envelopes obtained using a conventional DLL with a narrow spacing of $d=1/15$ chips (curve 101), the techniques representing the closest prior 10 art (curve 102) and the proposed new technique (curve 103). The curves are relative to a signal to multipath power ratio of 100. It can be seen that the proposed technique yields the best results for multipath delays shorter than about 20 m. Although the existing techniques perform 15 better for medium to large multipath delays, the new technique yields better results in real life situations because most of the multipath signals fall in the short delay region.

[0061] Also, contrary to prior art techniques, the 20 multipath estimation is filtered independently from the range measurement in the low-pass filter 24, allowing to use a low noise equivalent bandwidth B_n , and hence to keep the noise on the estimate low. This makes sense because 25 multipath errors typically only contain very low frequency components. As an illustration, it can be demonstrated that the standard deviation of the noise on the preferred multipath error estimator is given by:

$$\sigma_{MP} = 0.42\lambda_c \sqrt{B_n} \frac{N_0}{S} \sqrt{\frac{d(2-d)}{(1-d)^2}}$$

where $\lambda_c = 293$ m for the GPS C/A-code. As an example, σ_{MP} is 30 only 0.1m for $d=1/15$, $B_n=0.1$ Hz and a nominal C/N₀ of 45dB-Hz.

CLAIMS

1. A method for processing at least one signal sent by a transmitter, said signal preferably being used for measuring the range, i.e. the distance between 5 said transmitter and a receiver, said signal comprising a carrier signal modulated by a pseudo random noise (PRN) code, said method comprising the steps of :

- mixing said signal with a replica of the carrier signal, to acquire a baseband signal, representing said PRN 10 code,
- multiplying said baseband signal respectively with at least four PRN code replica's (P_{-M}, \dots, P_{+N}), said replica's being shifted in time with respect to each other,
- calculating the correlation values (I_{-M}, \dots, I_{+N}) of said 15 baseband signal with respect to each of said at least four PRN code replica's,
- calculating from said correlation values (I_{-M}, \dots, I_{+N}), an estimate of the multipath error, said calculation being based on a predefined formula, equating said multipath 20 error to a predefined function of said correlation values (I_{-M}, \dots, I_{+N}).

2. A method according to claim 1, comprising the steps of :

- mixing said signal with a replica of the carrier signal, to acquire a baseband signal, representing said PRN 25 code,
- multiplying said baseband signal respectively with three equally spaced replica's (P_0, P_{-1}, P_{+1}) of said PRN code, namely an early (P_{-1}), punctual (P_0) and late (P_{+1}) 30 replica, with a given early-late spacing (d),
- multiplying said baseband signal with at least one additional replica of said PRN code, said additional

replica being shifted in time relative to said early, late and punctual replica's,

- calculating the correlation values (I_{-M}, \dots, I_{+N}) of said baseband signal with respect to each of said at least 5 four PRN code replica's,
- locking the punctual code (P_0) to the baseband signal by keeping the two correlation values (I_{-1}, I_{+1}) between said baseband signal and said early and late replica's (P_{-1}, P_{+1}) equal to each other,
- 10 - calculating the range by multiplying the delay of the punctual code (P_0) by the speed of light,
- calculating from said correlation values (I_{-M}, \dots, I_{+N}), an estimate of the multipath error, said calculation being based on said predefined formula,
- 15 - filtering said estimate of the multipath error and subtracting said estimate of the multipath error from said calculated range, yielding a corrected range value.

3. A method according to claim 1 or 2, wherein said predefined formula is a linear combination of 20 said correlation values (I_{-M}, \dots, I_{+N}), each of said values being normalised by the correlation value (I_0) of said punctual replica (P_0).

4. A method according to claim 3, wherein said linear combination is of the following form :

25

$$MP = \sum_{i=-M..N} \alpha_i \frac{I_i}{I_0} \frac{1 - |i| \frac{d}{2}}{1 - |i| \frac{d}{2}}$$

wherein MP represents the multipath error, d represents the early-late spacing, I_0 represents the correlation value of 30 said punctual replica, I_{-M}, \dots, I_{+N} represent the correlation values, α_i represent one or more predefined values.

5. A method according to any one of claims 1 to 4, wherein every one of said at least four replica's is shifted over the same time delay with respect to the next and/or previous replica.

5 6. A method according to claim 5, wherein four replica's are used, and wherein the early-late spacing (d) is 1/15 of a chip length, and wherein the fourth replica (P_{+2}) is 1/15 of a chip length later than said punctual replica (P_0), and wherein said multipath error
10 estimation (MP) is calculated as :

$$MP = -0.42 \cdot \left(1 - \frac{I_{+2}}{I_0} \frac{1}{1-d} \right)$$

7. A receiver for ranging applications according to the method of claims 2 to 6, said receiver comprising a plurality of channels for detecting and
15 locking onto a plurality of PRN encoded signals, each channel comprising :

- a delay line (20), comprising at least four taps,
- a plurality of mixers (7) and accumulators (8) to calculate said at least four correlation values

20 (I_{-M}, ..., I_{+N}),

- a multipath estimator module (23) to calculate said multipath error estimate (MP),
- a low pass filter (24).

8. A receiver according to claim 7, wherein
25 said multipath estimator module (23) comprises software means for calculating the multipath error estimate on the basis of a predefined formula.

9. A receiver according to claim 7, wherein
said multipath estimator (23) module comprises hardware
30 means for calculating the multipath error estimate on the basis of a predefined formula.

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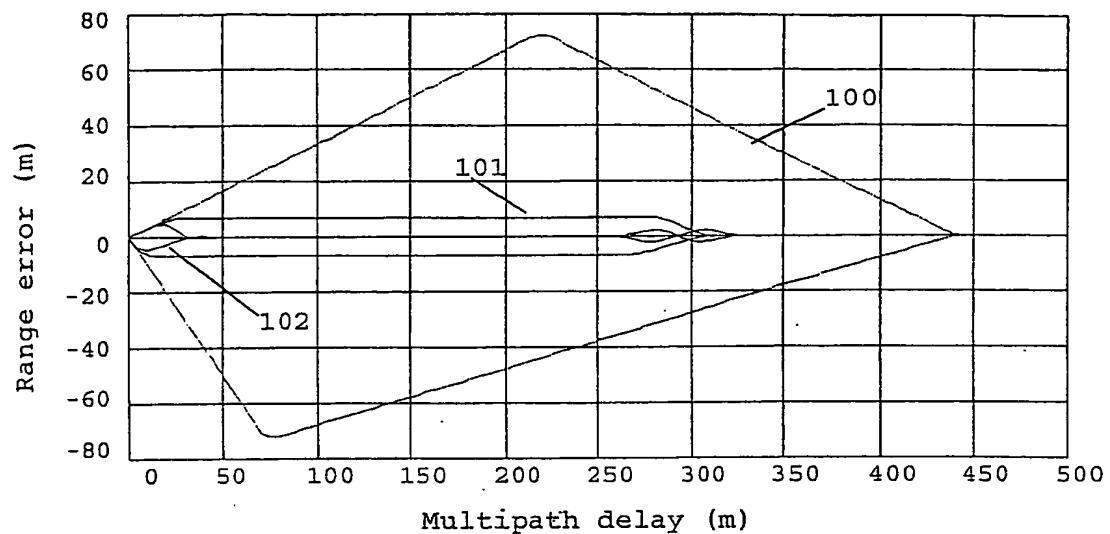
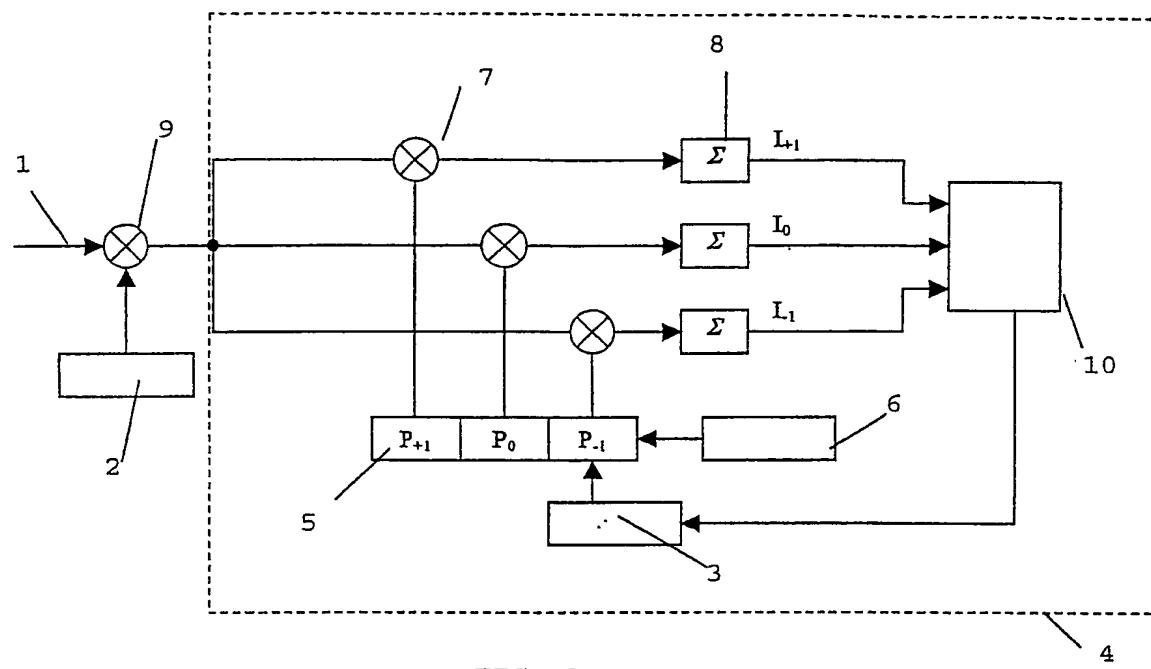


FIG. 1

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FIG. 2

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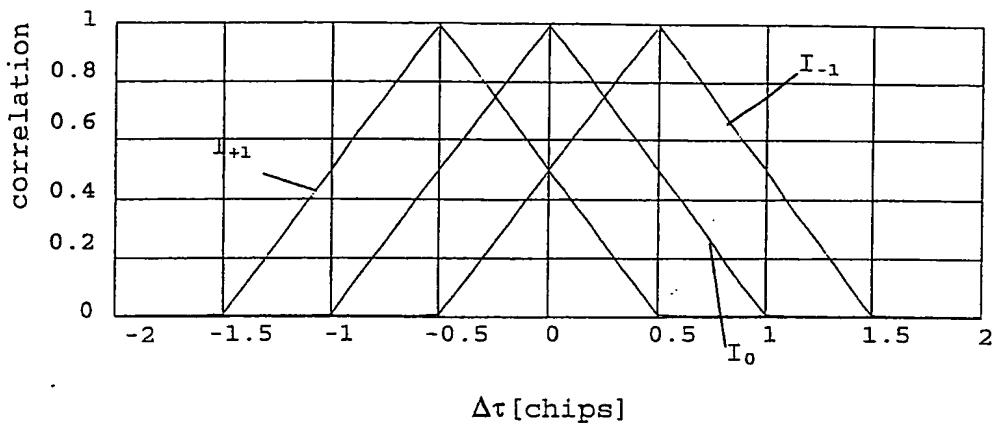


FIG. 3a

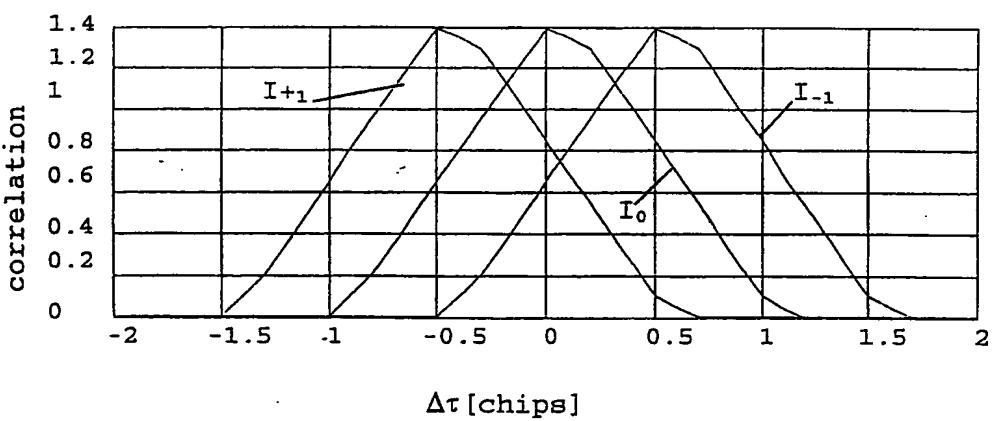


FIG. 3b

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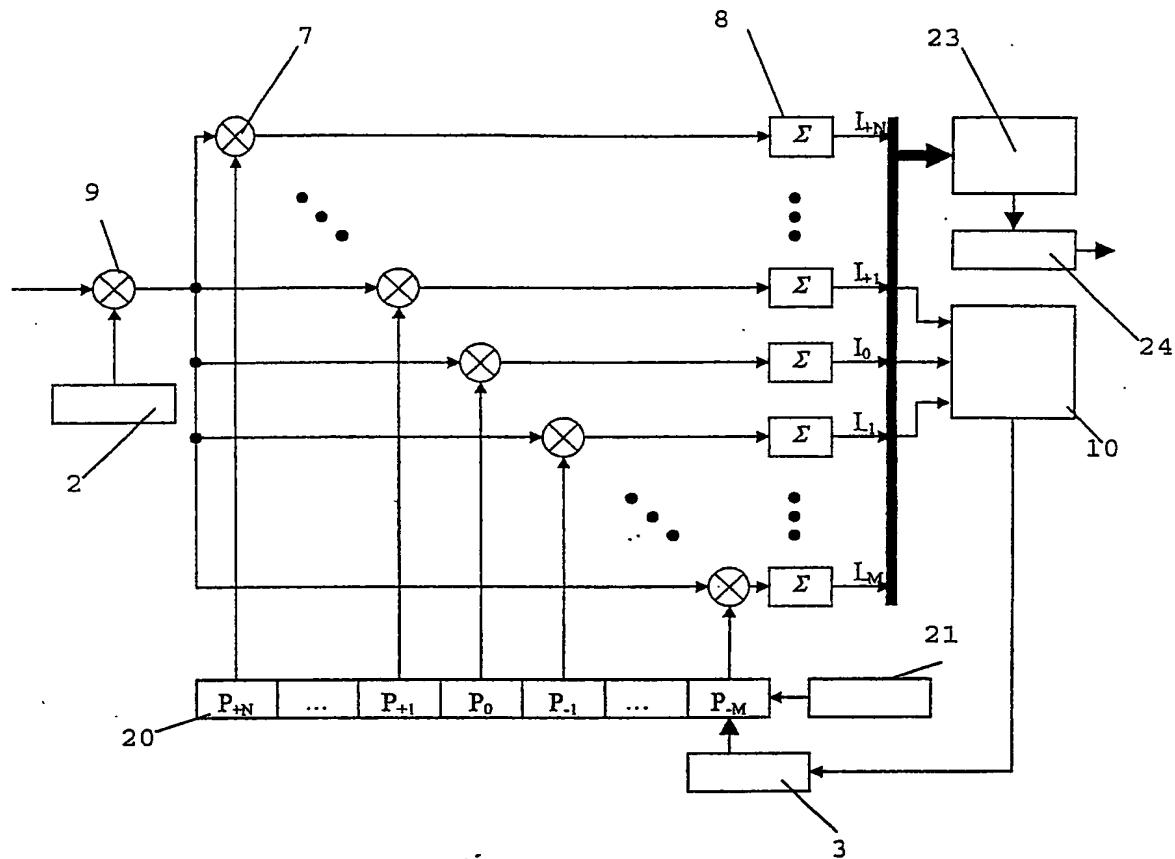


FIG. 4

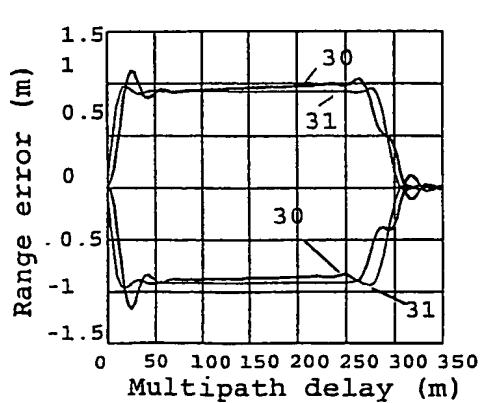


FIG. 5a

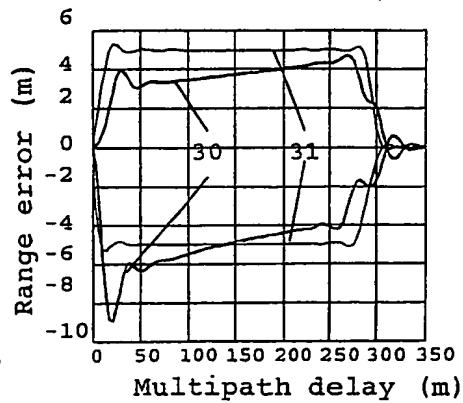


FIG. 5b

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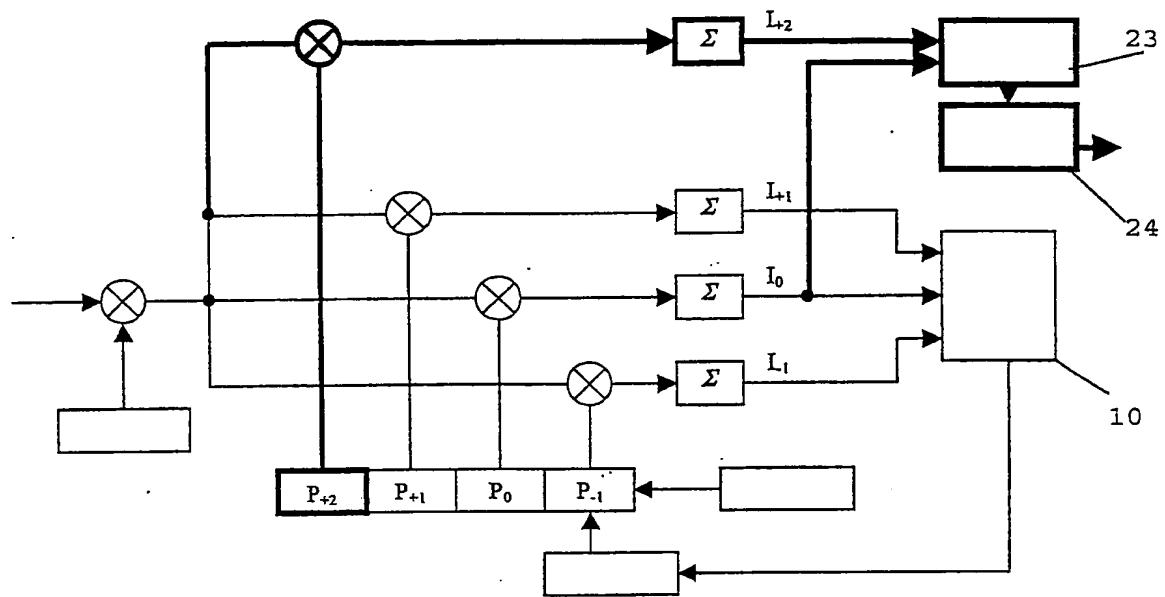


FIG. 6

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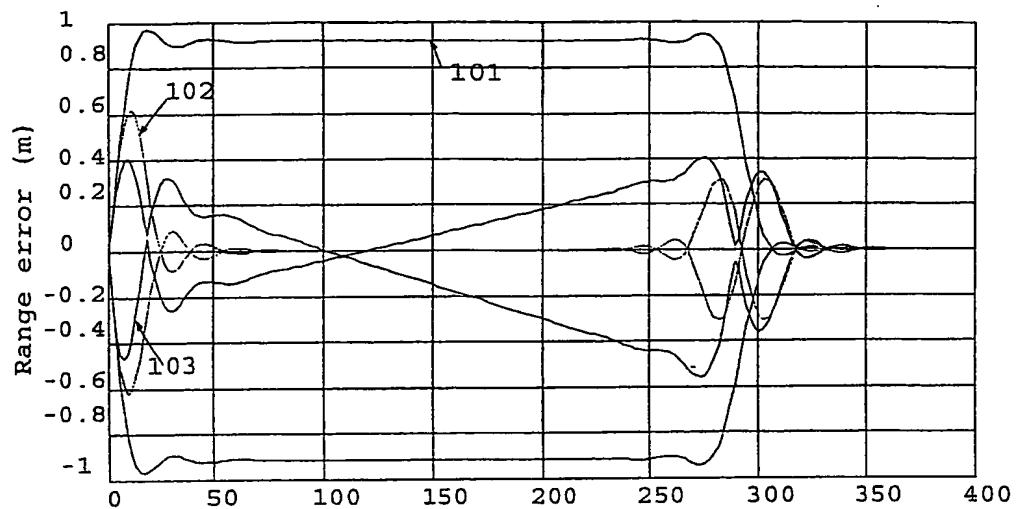


FIG. 7